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(54) Hydraulically powered drilling sub for deepwell drilling

(57) An hydraulically powered sub for deepwell drilling comprises a hydraulic rotary motor of the positive displacement type (such as a vane motor and a Moineau motor).

The outer surface of the housing of the motor is provided with sections having the outer surface thereof at various radii with respect to the central axis of the housing. The large-radius sections form stabiliser wings and house at least part of the hydraulic motor, such as hydraulic conduits, vanes, slots for vanes, or fluid compartments.

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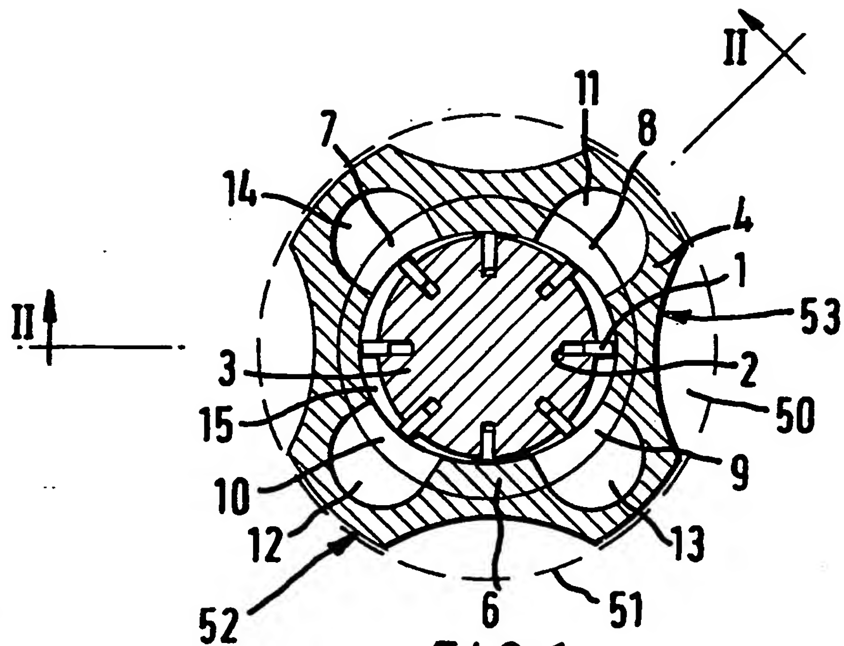


FIG.1

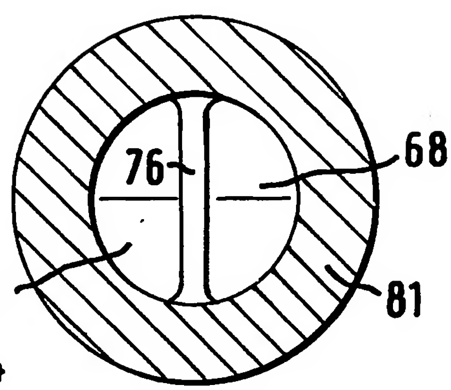


FIG.4

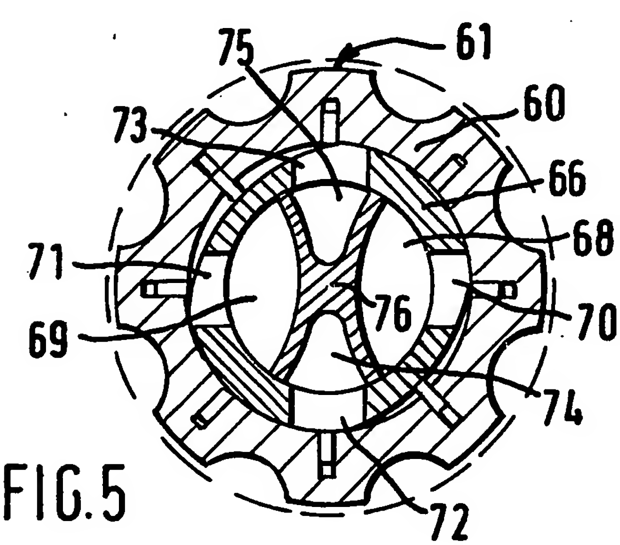
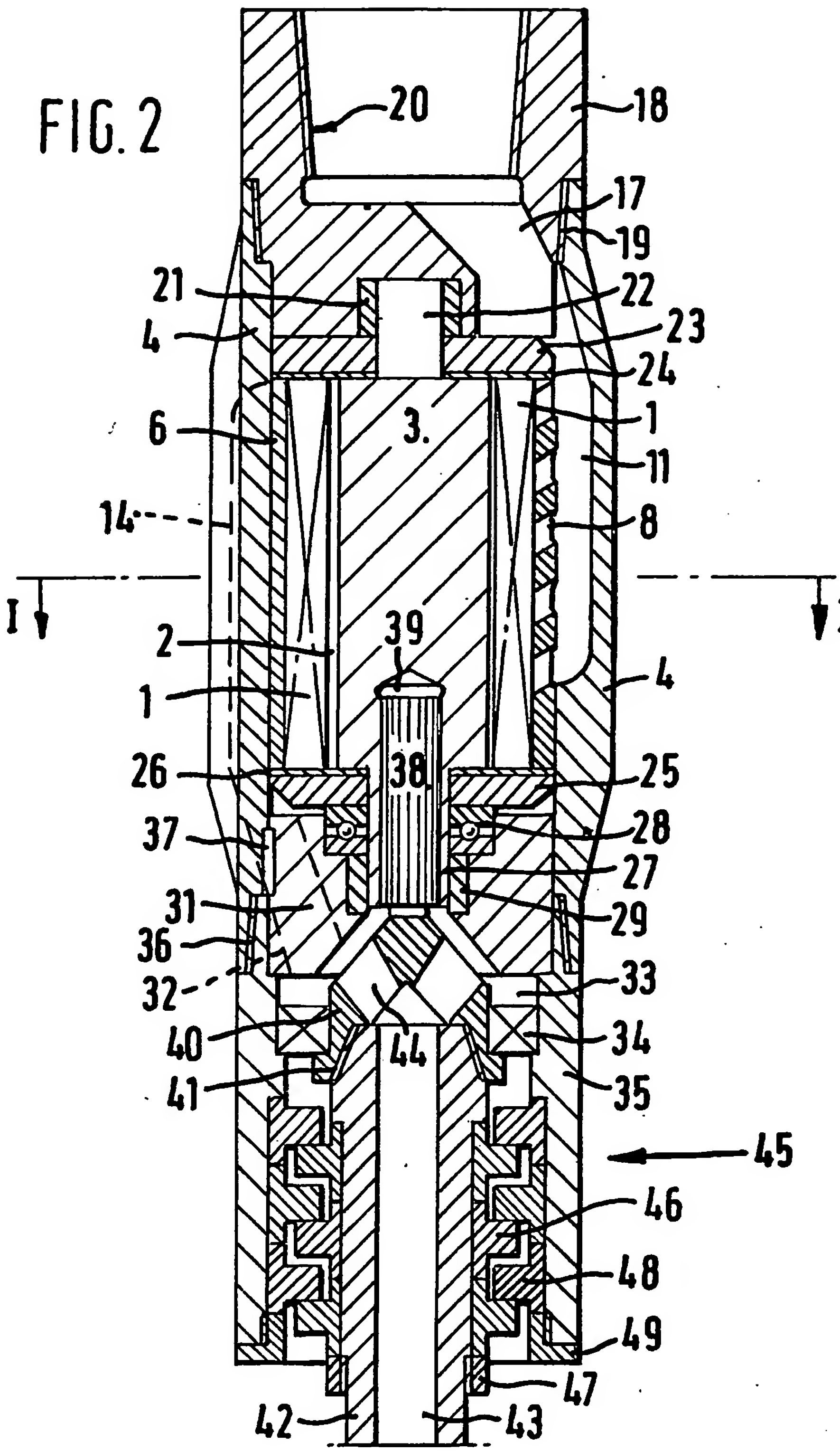


FIG.5

FIG. 2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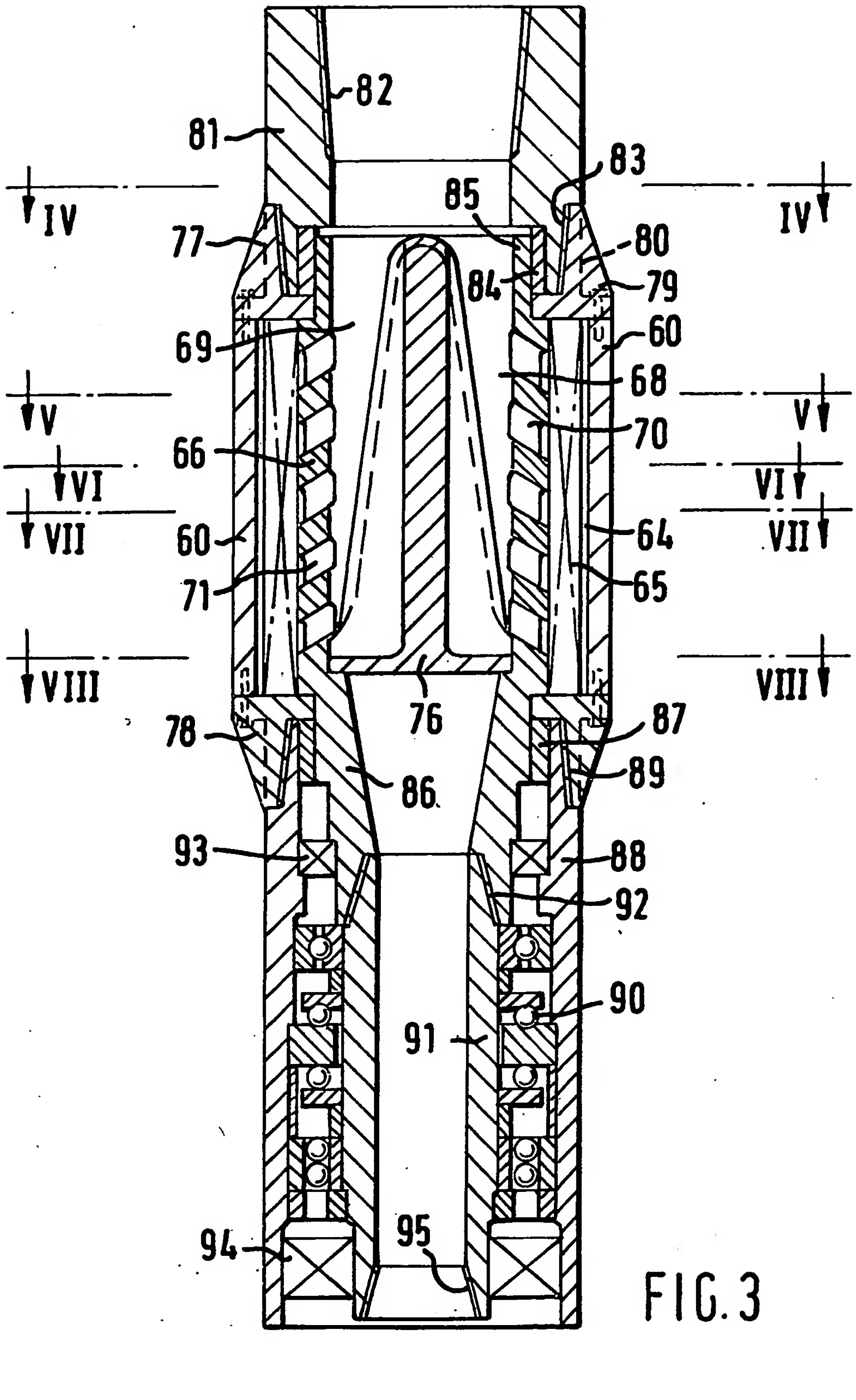
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FIG. 3

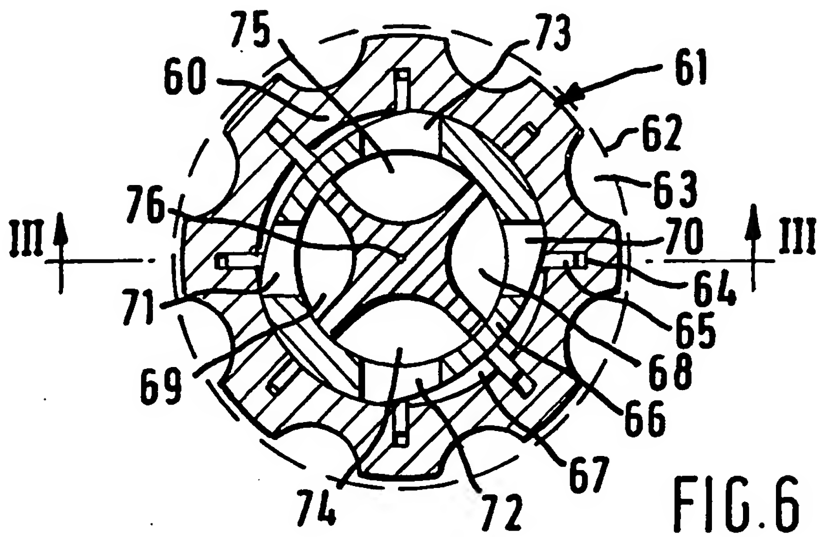

FIG.6

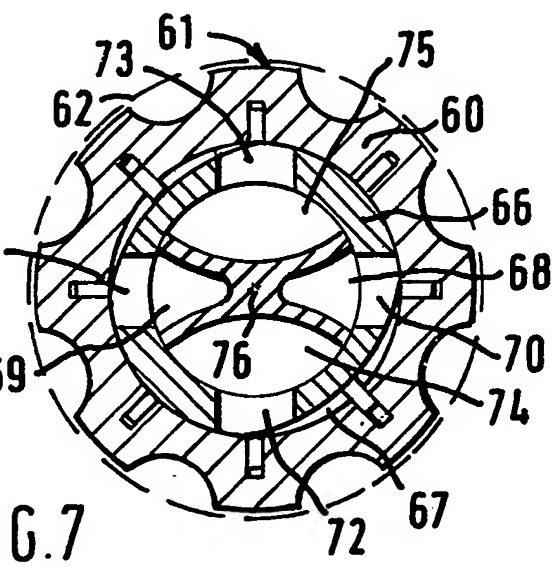

FIG.7

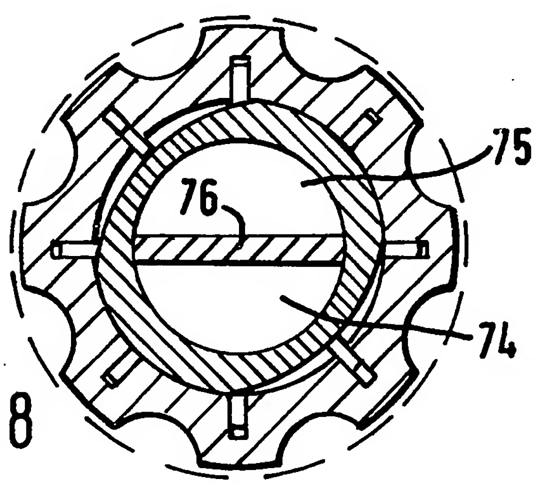

FIG.8

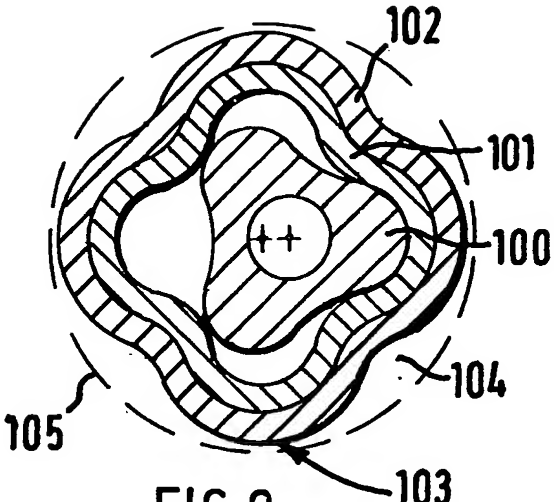

FIG.9

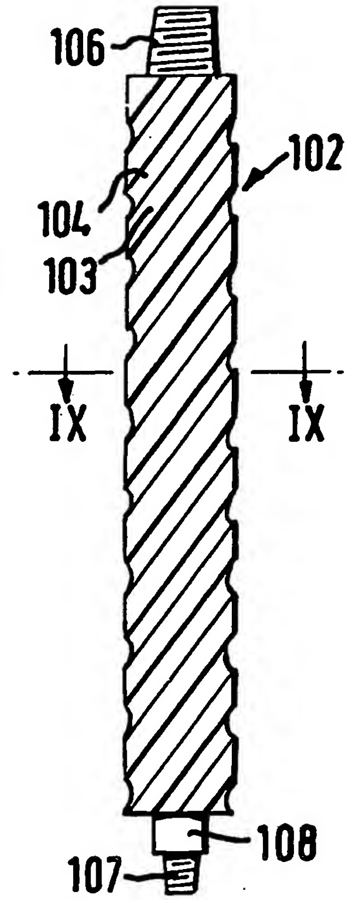

FIG.10

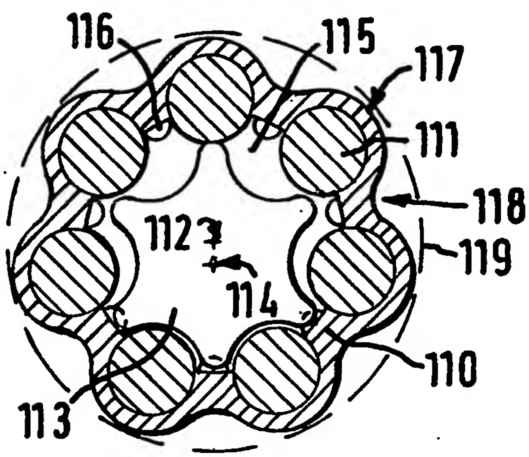

FIG.11

SPECIFICATION

Hydraulically powered drilling sub for deepwell drilling

The invention relates to a hydraulically powered drilling sub for deepwell drilling, in particular for drilling boreholes in subsurface formations for forming wells through which fluids such as oil, gas or (hot) water may be recovered from said formations. The drilling sub is also useful in carrying out exploration work in such formations.

Hydraulically powered drilling subs including mud-driven hydraulic motors have been described already in numerous earlier publications. Such motors are either turbine motors or positive displacement motors (such as vane-type motors and motors of the Moineau-type).

The subs have coupling means for coupling the sub to drilling means. Such drilling means include a drill string, a drill collar string and a rotary bit, and the sub is preferably placed between the rotary bit and the lowermost drill collar of the drill collar string, or between a pair of drill collars.

The invention relates in particular to a hydraulically powered drilling sub including a hydraulic rotary motor of the positive displacement type. The positive displacement motor includes a stator housing with a central axis, the housing being provided with coupling means adapted to connect the housing directly or indirectly to one part of the drilling means such that the central axis of the housing coincides with the axis of rotation of the drilling means. The motor further includes a rotor rotatably arranged within the stator housing, coupling means adapted to connect the rotor directly or indirectly to the other part of the drilling means, fluid compartments between the inner wall of the stator housing and the outer wall of the rotor, and conduits for passing fluids into and out of the compartments.

The power P developed by a hydraulic motor of the positive displacement type is directly related to the flow rate F of the fluid through the motor and the diference in pressure Δp existing between the fluid present in the inlet conduit and the outlet conduit through which the fluid is passed into and out of the fluid compartments, respectively.

Hence,

$$P \sim F \cdot \Delta p \qquad (1)$$

Further, the mathematical product of the number of revolutions R of the motor and that part V of the volume of the fluid compartments that is displaced per single revolution of the motor is directly proportional to the flow rate F.

Hence,

$$F \sim V \cdot R \qquad (2)$$

The displaced volume V of the compartments per revolution of the motor is referred to hereinafter and in the claims as the "volume" V of the compartments. Further, the expression "volume per unit length" v is introduced, that is the displaced volume of the compartments per unit length thereof (measured in a direction parallel to the central axis of the housing).

Hence,

$$V = v \cdot L \qquad (3)$$

wherein L is the length of the fluid compartments.

By introducing formulas 2 and 3 into formula 1, it follows that

$$P \sim v \cdot L \cdot R \cdot \Delta p \qquad (4)$$

and

$$T \sim \frac{P}{R} \sim v \cdot L \cdot \Delta p \qquad (5)$$

wherein T is the torque developed by the motor.

It will be appreciated that since the motors have to operate in boreholes of relatively small cross-sections, the known motors have the disadvantage that the volume per unit length thereof (which is indicated by the symbol "v" in the above formulas) is relatively small.

The object of the invention is a hydraulically powered sub comprising a positive displacement motor with compartments having an increased volume per unit length when compared with the compartments of the known motors.

As can easily be seen from formula 5, an increase of v in motors of a given length will result in an increase of T. If power P is kept constant, an increase of v will result in a reduction of R, which allows the use of a reduction gearbox of smaller dimensions, or even the deletion of the gearbox.

As can further easily be seen from formula 3, built at a reduced length L when compared to known motors. Simpler construction and manufacturing techniques may then be applied which will reduce manufacturing costs.

The hydraulically powered drilling sub for deepwell drilling according to the invention includes a hydraulic rotary motor of the positive displacement type as described above, wherein the outer wall of the stator housing forms at least part of the outer wall of the sub and is provided with sections having the outer surface thereof situated at various radii with respect to the central axis of the housing, the ratio between the minimum and the maximum radii being at most 0.95, the large-radius sections forming stabilizer wings, and at least part of these latter sections housing at least parts of the hydraulic rotary motor.

The hydraulic motor may be a vane-type motor having the vanes thereof slidably arranged in slots carried by the rotor. The large-radius sections then house at least part of the fluid conduits.

In another embodiment of the invention, the hydraulic motor is a vane-type motor having at least part of the fluid conduits arranged inside the rotor. The large-radius sections then house slots wherein vanes are slidably arranged.

In still another embodiment of the invention, the hydralic motor is a Moineau-type motor. The large-radius sections are then helically shaped and enclose part of the compartments between the rotor and stator housing.

In again another embodiment of the invention, the hydraulic motor comprises a rotor having a toothed outer surface co-operating with a plurality of cylindrical bodies that are positioned at regular distances from one another along the inner wall of the stator housing. Each such body is then positioned in a large-radius section of the stator housing.

It will be appreciated that for a given hole diameter the use of a stator housing having large-radius sections, locally increases the radius of the housing when compared to circle cylindrical stator housings of prior art hydraulically powered drilling subs. The sections having relatively large radii act as stabilizer wings which can house parts of the hydraulic motor, whereby the compartments of the motor obtain an increased volume per unit length when compared to prior art motors. The stabilizer wings stabilize the sub against horizontal deflection in the hole that is being drilled. If straight sections are used, at least three large-diameter section should be provided in order that these sections will act as stabilizer wings. Generally four or more of these sections will be applied, such as from four to eight sections. If helically shaped sections are used, such as in connection with Moineau-motors, the number of sections is equal to the number of lobes of the stator. Such stator has at least two lobes.

The invention will be described by way of example in more detail with reference to the drawings.

Figure 1 shows schematically a cross-section over a hydraulically powered drilling sub according to the invention, incorporating a sliding vane-type hydraulic motor wherein the sliding vanes are carried by the rotor thereof.

Figure 2 shows a longitudinal section of the drilling sub of Figure 1, taken over section II—II thereof.

Figure 3 shows schematically a longitudinal section over a drilling sub according to the invention of alternative design, wherein the sliding vanes are located in slots situated in the housing of the motor.

Figures 4—8 shows cross-sections of the drilling sub of Figure 3, taken over sections IV—IV, V—V, VI—VI, VII—VII, and VIII—VIII respectively.

Figure 9 shows schematically a cross-section over a hydraulically powered drilling sub according to the invention, incorporating a hydraulic motor of the Moineau-type.

Figure 10 is a side view of the sub of Figure 9.

Figure 11 shows schematically a cross-section over a drilling sub according to the invention, incorporating a hydraulic motor of the internal gear type.

The hydraulically powered drilling sub of Figures 1 and 2 has the vanes 1 thereof slidably arranged in the slots 2 of the rotor 3. The vanes are pushed against the inner wall of the housing 4 by springs (not shown) arranged between the vanes and the bottom parts of the slots. The inner wall of the housing 4 is constituted by a wear-resistant lining 6 provided with openings 7, 8, 9 and 10. Fluid supply conduits 11, 12 in the housing 4 communicate with the openings 8 and 10, respectively, and fluid discharge conduits 13, 14 in the housing 4 communicate with openings 9 and 7, respectively.

The space between the outer wall of the rotor 3 and the inner non-cylindrical wall of the lining 6 of housing 4 consists of two parts with crescent-shaped cross-section, which parts are divided into a plurality of compartments 15 by the vanes 1. It will be appreciated that the total volume of the compartments is constant, but that the volume of each compartment varies between approximately zero to a maximum value when the rotor 3 is rotated in the housing 4 around its central axis. Fluid supplied through supply conduits 11 and 12 will enter the compartments 15 that are in communication with the ports 8 and 10, respectively, and activate the rotor 3 to rotate around its central axis. The compartments 15 that are in communication with the fluid discharge conduits 13 and 14 will exhaust in these conduits through the ports 9 and 7, respectively.

The supply conduits 11 and 12 via which liquid is supplied to the ports 8 and 10, respectively, communicate with passages 17 (one of which is shown in Figure 2) in the tubular member 18 that is connected to the upper end of the housing 4 by means of a screw thread 19. The tubular member 18 is provided with an internal screw thread 20 for connecting the hydraulically powered drilling sub to drilling means (not shown) such as the lower end of a drill collar. A bearing 21 is carried by the tubular member 18, and the shaft 22 of the rotor 3 is rotatably supported by said bearing 21. A cheek plate 23 with wear-resistant lining 24 is arranged between the tubular member 18 and the rotor 3. The upper end of the slots 2 housing the vanes 1, as well as the upper end of the space consisting of compartments 15 are sealed off by said cheek plate 23.

A second cheek plate 25 with wear-resistant lining 26 is arranged at the lower end of the rotor 3 for closing off the lower ends of the slots 2 and the space consisting of compartments 15. This lower end of the rotor 3 is provided with a shaft 27 that is supported by bearing 28 and 29 that are housed in tubular member 31.

Two passages 32 (only one of which is shown in broken lines) are arranged partly in the lower end of the housing 4 and partly in the tubular member 31, each of said passages communicating at one end thereof with one of the discharge conduits 13 and 14, and with the other ends thereof with the space 33 above the sealing member 34 in the tubular member 35 that is coupled to the housing 4 by means of a screw thread 36. Tubular member 31 is being prevented from rotation with respect to the housing 4 by means of a key 37.

A splined shaft 38 cooperating with a splined opening 39 in the lower end of the rotor 3, is attached to the member 40 that is connected by a screw thread 41 to the drill shaft 42 having a central bore 43. Space 33 communicates with the central bore 43 via openings 44 in member 40. Any liquid that is leaving the compartments 15 can thus flow via drain conduits 13 and 14, channels 32, space 33, openings 44 and central bore 43 to a rotary drilling bit (not shown) that is coupled to the lower end of the drill shaft 42. Axial loads between the shaft 42 and the housing 4 are taken up by the thrust bearing 45 comprising a plurality of spacer rings 46 mounted on the drill shaft 43 by means of a screw ring 47, and a plurality of spacer rings 48 cooperating with the rings 46 and mounted inside the tubular member 35 by means of a screw ring 49. Cooperating surfaces of the rings 46 and 48 may be provided with wear-resistant lining (not shown) and suitable channels or passages (also not shown) may be arranged for supplying liquid to the thrust bearing 45 for cooling and lubricating purposes. This type of thrust bearing is known per se and does not require a detailed description.

As can best be seen in Figure 1 of the drawings, the cross-section of the housing 4 is such that passages 50 are present between the outer wall of the housing 4 and the inner wall of the borehole (see broken line 51). The housing 4 thereby acts as a stabilizer when the sub is being operated in the hole 51. The passages 50 are used for the return flow of the mud through the borehole 51. The four large-radius sections 52 of the housing 4 form wings that stabilize the hydraulic sub and the drilling bit driven thereby in the borehole, whereby horizontal deflection of the borehole is prevented, or at least minimized.

The ratio between the smallest radius of each of the sections 53 located between twc of the large-radius sections 52 is at most 0.95.

By arranging the conduits 11—14 in the large-diameter sections 53 of the housing 4 that forms the stabilizer wings, the radius of the lining 6 can be increased as compared to prior art hydraulically powered drilling subs that incorporate vane-motors with housings having cylindrical outer walls. This allows an increase of the volume of the compartments per unit length of the rotor, whereby the advantages as explained hereinbefore will be gained.

In an alternative embodiment of the invention, as shown in Figures 3—8 of the drawings, the large-radius sections of the housing of the vane-motor form stabilizer wings and house the slots of the vanes. The same advantages as referred hereinabove are then obtained.

The hydraulically powered drilling sub of Figure 3—8 comprises a housing 60 (see in particular Figure 3 and Figure 6, which latter figure shows a cross-section over the motor of Figure 3 taken at the level of the middle of the rotor thereof) comprising eight large-radius sections 61. These sections are of slightly smaller radius than the borehole 62, and each space 63 enclosed by a pair of sections 61 nearest thereto and by the borehole wall acts as a return passage for the mud in the hole 62.

Each large-radius section 61 houses a slot 64 in which a vane 65 is slidably arranged. Springs (not shown) are arranged between the bottom of each slot and the vane in said slot. A rotor 66 is arranged in the bore of the housing 60, and the space between the rotor 66 and the housing 60 is divided into a plurality of compartments 67 by the vanes 65. The central axes of the rotor 66 and of the housing 60 coincide and the outer wall of the rotor 66 is shaped such that the volumes of the various compartments 67 vary when the rotor 66 is rotated. Rotation of the rotor is brought forward by the supply of pressure liquid via the channels 68 and 69 in the rotor 66. This liquid passes through ports 70 and 71, respectively, that are arranged in the wall of the rotor 66. After passing through the compartments 67 in the space between the rotor 66 and the housing 60, the liquid is discharged via the ports 72 and 73, respectively, and leaves the vane motor through discharge channels 74 and 75 that are arranged within the rotor 66.

The supply channels 68, 69 and the discharge channels 74, 75 are formed by the insert piece 76 that is situated in the central bore of the rotor 66. This insert piece 76 consists of four walls that form the supply channels 68, 69 such that the cross-section of each channel decreases in downward direction (see Figure 4—8). Since each channel communicates with a row of ports 70—73, and each row extends in longitudinal direction along a channel, the flow of liquid through each channel will be approximately equal along the length of each channel. The fluid pressure at each inlet port of the rows of inlet ports 70, 71 will therefore be substantially equal. Also, the fluid pressure at each outlet port of the rows of outlet ports 72, 73 will therefore be substantially equal. As a result thereof, each blade 65 will be subjected to a uniform driving pressure over its length.

The insert piece 76 is sealingly connected to the wall of the central bore of the rotor 66, and secured against axial as well as rotational displacements within said bore.

The slots 64 and the compartments 67 are sealed off at the upper and lower ends thereof by cover elements 77, 78, respectively (see Figure 3). These elements are connected to the housing 60 by a plurality of locking nuts 79 passing through holes in recessed parts 80 (see broken lines) of the elements 77, 78 and screwed in screw-threaded holes arranged in the stator housing 60. A coupling element 81 provided with an internal screw thread 82 for connecting the hydraulically powered drilling sub to a drill collar is connected to the cover element 77 by means of a screw thread 83. Element 81 is provided with a bearing 84 for supporting the upper shaft 85 of the rotor 60.

The lower shaft 86 of the rotor 60 is supported by a bearing 87 carried by the sleeve member 88

that is connected to the cover element 78 by means of a screw thread 89. The sleeve member 88 houses a thrust bearing 90 for transmitting axial loads between the drill shaft 91 and the housing 60. The drill shaft 91 is coupled to the lower end of the rotor shaft 86 by means of a screw thread 92, and the space between the drill shaft 91 and the bushing 88 is filled with lubricant and closed off by seals 93, 94 that are kept in place in an appropriate manner such as by snap-rings (not shown).

The lower end of the shaft 91 is provided with a screw thread 95 for coupling a (not shown) drill bit to this shaft.

The embodiment of the invention shown in Figures 3—8 has the slots 64 of the vanes 65 arranged in the large-radius sections 61 of the housing 60, which sections acts as stabilizer wings. By this arrangement of the vanes, the compartments 67 have a large volume per unit length. The advantages thereof have already been explained hereinbefore.

Although the embodiments shown by way of example in the drawings both show a hydraulically powered drilling sub wherein the vane motor comprises rigid vanes that are slidably arranged in slots, the invention is not limited to this type of vanes. Equal good results will be obtained when applying the invention in a hydraulically powered drilling sub having a vane motor with flexible vanes. These vanes may be formed by flexible sheets that are connected to the rotor (or to the housing) along one longitudinal edge thereof. Also, such vanes may consist of rigid elongate elements that are hingedly connected (such as by means of a flexible sheet) to the housing or rotor of the vane motor. Examples of flexible vanes are shown in U.S. patent specifications Nos. 2,655,344 and 3,304,838; and German patent specification 1,025,359. In again another embodiment of the invention, the vanes may be formed by cylindrical bodies that have the central axes thereof parallel to the central axis of the rotor. An example of this type of motor is described in British patent specification 1,443,674.

The two embodiments shown in Figures 1—8 of the drawings incorporate balanced vane motors having two sets of inlet ports and two sets of outlet ports. Multi-balanced vane motors may be applied as well, such as motors having three sets of inlet ports and three sets of outlet ports. It is observed that unbalanced motors having a single set of inlet ports and a single set of outlet ports are often liable to jamming of the rotor in the housing and therefore not preferred.

The vanes may be pressed for sealing purposes against the inner wall of the housing (when the vanes are mounted in the rotor or against the outer wall of the rotor (when the vanes are mounted in the housing) by springs mounted between the vanes and the bottom of the slots as well as by any other means suitable for the purpose. Such means are known per se and do not need a detailed description.

Wear-resistant liners and/or coatings may be applied to those surfaces where excesively large wearing forces will be generated. Suitable materials for such liners and coatings as well as treating methods for increasing the resistance against wear of materials are known and these may be applied in the drilling sub of the present invention where such is deemed necessary. In particular, such wear-resistant linings may be used for covering the stabilizer wings over those areas where the wings contact the borehole wall during drilling operations.

The present invention may further be applied to hydraulically powered drilling subs comprising one or more positive displacement motors of the Moineau-type, wherein each motor comprises a helically-shaped stator. A plurality of fluid compartments is formed between the rotor and the stator, which compartments are displaced helically around the central axis of the Moineau-motor when the rotor is displaced in the stator. During such displacement, the rotor rotates around its axis and simultaneously orbits around the central axis of the stator, and the torque exerted on the rotor by the drilling fluid is transferred via a flexible or universal coupling to a shaft that is supported axially within the lower end of the stator housing and adapted to be connected to a drill bit.

Figure 9 of the drawings shows a cross-section over a drilling sub with a hydraulic motor of the Moineau-type, wherein a three-lobed rotor 100 cooperates with a four-lobed stator 101.

In the embodiment shown, the rotor 100 is made of metal, such as steel, whereas the stator 101 is of flexible material, such as rubber or an elastomer material. The stator 101 is supported in a stator housing 102 having helical large-radius sections 103 as can best be seen in Figure 10 which shows a side view of the motor of Figure 9. Figure 9 shows a cross-section of the motor taken over section IX—IX of Figure 10. The section 103 of the stator housing 102 have helical grooves 104 therebetween which allows return mud to pass alongside the housing 102 when the motor is operating in a hole 105 (see broken line in Figure 9). The space within the large-radius section 103 is used for housing the lobes of the stator 102 and it will be appreciated that the volume per unit length of the compartments of the Moineau-motor is considerably increased in this manner when comparing it with prior art Moineau-motors designed for the same drilling diameter.

The stator housing 102 is provided with a screw-threaded coupling 106 by which the Moineau-motor can be coupled to the drill string, whereas the screw-threaded coupling 107 on the rotatable shaft 108 can be connected to a rotary bit. As mentioned already hereinabove, the shaft 108 is coupled to the rotor 100 by means of a flexible coupling (not shown). Since all these details of the Moineau-motor are known per se, they are not discussed here in detail.

Finally, Figure 11 of the drawings shows a cross-section over a drilling sub with a hydraulic

motor of the internal gear type. This motor includes a stator housing 110 and an outer gear set consisting of rollers 111 arranged parallel to the central axis 112 of the stator housing at regular distances from each other. A part of each roller is enclosed by a cylindrical bearing formed in a recess in the wall of the stator housing 110. The rollers are rotatably arranged in the bearings and cooperate with an inner gear set formed by the toothed rotor element 113 that is adapted to rotate around the central axis 114 thereof and to orbit simultaneously around the central axis 112 of the stator housing 110. Fluid compartments 115 are present between the rotor element 113, the stator housing 110 and the rollers 111, the pressure fluid can be supplied to these compartments via the opening 116 that are arranged at one end of the compartments. The passage through these openings is controlled by a valve plate (not shown) that is rotated in conjunction with the rotor 113. Similar valve controlled openings (not shown) are further provided at the other end of the compartments 115. The valve plates control the entry of high pressure fluid into the compartments and the exhaust thereof from the compartments as a result whereof the rotor 113 carries out a rotational and orbital movement. The rotor is coupled to the drilling shaft by (not shown) gear means or a (not shown) shaft via universal coupling means, and on movement of the rotor, the theeth thereof co-operate with the rollers 111. A more detailed description of this type of hydraulic positive displacement motor can be found in U.S. patent specification 3,289,602 (patented 6th December, 1966, Inv. Bernard C. Hudgens, assignor to TRW Inc.).

In accordance with the invention, the outer wall of the stator housing 110 of the motor shown in Figure 11 comprises large-radius sections 117 that house the rollers 111 of the motor. Between the eight large-radius sections 117 there are eight small-radius sections 118 along which return mud can flow between the outer wall of the sub and the wall 119 of the borehole.

It will be appreciated that the shape of the non-cylindrical outer walls of the stator housings that form at least part of the outer wall of the hydraulically actuated drilling subs according to the invention should be chosen such that a passagway of sufficient cross-section for allowing the flow of return mud is left between the outer wall of the stator housing and the wall of the borehole in which the motor is operating. To this end, the ratio between the minimum radius and the maximum radius of the outer wall of the stator housing should be not larger than 0.95. The large-radius sections of the housing, which form the stabilizer wings, may have a diameter that is slightly less than the hole diameter (say, between 98.0 and 99.6% thereof) whereas the small-radius sections situated between the wings form the passage ways for the return mud. It will be understood that the ratio between the minimum radius and the maximum radius of the outer wall of the stator housing is further selected in dependence on the number of wings and size thereof in tangential direction with respect to the stator housing. When increasing the number of wings and/or increasing the width of the wings, lower ratios should be applied, such as between 0.85 and 0.75 in order to create a return mud passage of sufficient area.

CLAIMS

1. A hydraulically powered drilling sub for deepwell drilling, including a hydraulic rotary motor of the positive displacement type, the motor including a stator housing with a central axis, the housing being provided with coupling means adapted to connect the housing directly or indirectly to one part of drilling means such that the central axis of the housing coincides with the axis of rotation of the drilling means, the motor further including a rotor rotatably arranged within the stator housing, coupling means adapted to connect the rotor directly or indirectly to the other part of the drilling means, fluid compartments between the inner wall of the stator housing and the outer wall of the rotor, and conduits for passing fluids into and out of the compartments, wherein the outer wall of the stator housing forms at least part of the outer wall of the sub and is provided with sections having the outer surface thereof situated at various radii with respect to the central axis of the housing, the ratio between the minimum and the maximum radii being at most 0.95, the large-radius sections forming stabilizer wings, and at least part of these latter sections housing at least part of the hydraulic rotary motor.

2. The drilling sub according to claim 1, wherein the motor is a vane-type motor having vanes slidably arranged in slots carried by the rotor, and the large-radius sections house at least part of the conduits.

3. The drilling sub according to claim 1, wherein the motor is a vane-type motor having at least part of the conduits arranged inside the rotor, and the large-radius sections house slots wherein vanes are slidably arranged.

4. The drilling sub according to claim 3, wherein the rotor comprises a body with a central bore, said body having at least two rows of openings extending along the length of the rotor, said rows of openings alternately communicating with one of the end-parts of the rotor via conduits that are formed inside the bore by a body that is sealingly mounted inside the bore, and each of said conduits increasing in cross-section from zero to a maximum value in the direction of one of the end-parts of the rotor.

5. The drilling sub according to claim 1, wherein the motor is a Moineau-type motor, a large-radius sections are helically shaped and enclose part of the compartments between the rotor and stator housing.

6. The drilling sub according to claim 1, wherein the motor comprises a rotor having a toothed outer surface cooperating with a plurality

of cylindrical bodies that are positioned at regular distances from one another along the inner wall of the stator housing, each body being situated in a hollow space of a large-radius section.

7. The drilling sub according to any one of the claims 1—6, wherein the stabilizer wings are at least partly covered by a wear-resistant material.

8. Hydraulically powered drilling sub for deepwell drilling, substantially as described in the specification with reference to Figures 1 and 3, Figures 3—8, Figure 9 and 10, and Figure 11 of the drawings.

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